SILO PRESSURES AND TEMPERATURES WITH CORN AND GRASS SILAGE

A paper presented before the North Atlantic Section of the American Society of Agricultural Engineers, at Boston, Massachusetts, Tuesday, September 20, 1938, by J. R. McCalmont of the Bureau of Agricultural Engineering, U. S. Department of Agriculture, and H. E. Besley of New Jersey State Agricultural College.

A study of the pressures exerted by corn silage in round silos was started by the Bureau of Agricultural Engineering, in the fall of 1936.

This study came to the attention of Mr. Krueger at the New Jersey State Experiment Station, who knew of several failures of silos used for hay and molasses silage. The outgrowth of correspondence between Mr. Krueger and the Bureau regarding pressures in silos filled with such material was a cooperative study on grass silage pressures at the New Jersey North Branch experiment station.

Since the system used to measure the pressures exerted by both corn and grass silage was the same the pressure panel setup used for corn silage at Beltsville will be described, and for comparison the pressures in corn silage given.

The setup for measuring pressures was the same as used by this Bureau to determine the pressures exerted by ear corn in cribs, reported in the Journal of the American Society of Agricultural Engineers for November, 1934. In the present study the pressure panels replaced the regular silo doors. Special door jambs of 2" channel sections were introduced to support the panels on 5/8" round steel rods. The panels were made up like regular silo doors except that a half inch clearance was allowed around each door. Two lengths of 3-inch T section were bolted vertically to each door 12 inches outside to outside faces, each having 3/4-inch holes drilled 2 inches from the door and 6 and 1/8 inches on either side of the horizontal center line of the door. Figure 1 shows sections thru the doors and door opening and a view of the door. The 5/8-inch rods passed thru the 3/4-inch holes in the T sections bolted to the doors and rested in 3/4-inch holes drilled in the 2-inch channel section door jamb. The doors were covered inside with a strip of copper armored fiber paper creased to allow freedom of movement in the panels.

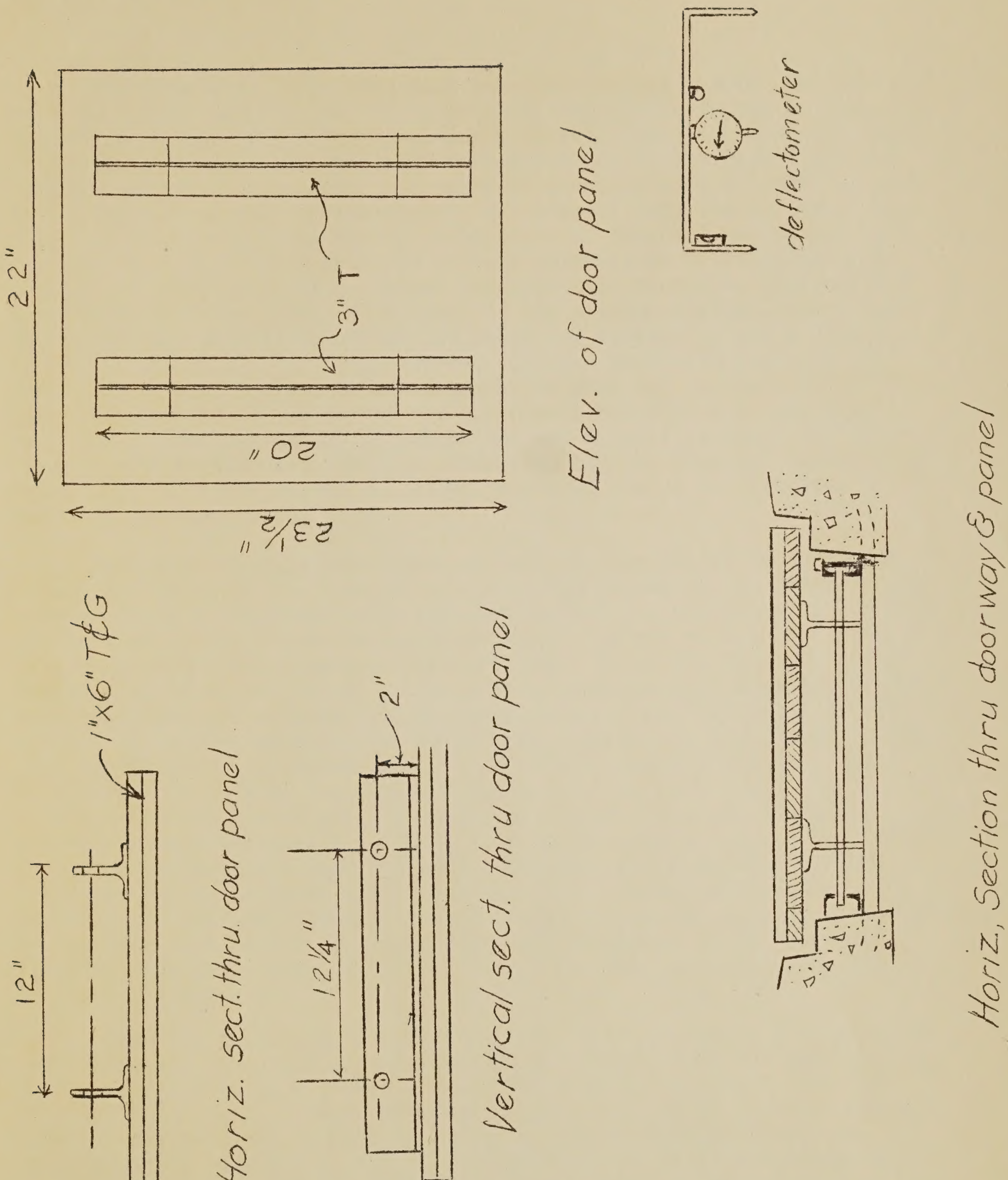

22"
3" T
20"
23½"
Elev. of door panel
deflectometer
12"
1"x6" T&G
Horiz. sect. thru door panel
12¼"
2"
Vertical sect. thru door panel
Horiz. Section thru doorway & panel

Fig. 1

The rods were calibrated on a standard testing machine for twice the expected loads, using points of loading and support identical to those in the actual setup. The deflection over a 10-inch gage length at the center of the rod was taken with the deflectometer shown in figure 1 which was equipped with both horizontal and vertical level glasses and with an Ames dial graduated to read deflections to the nearest .0001 of an inch. The rods were heat treated to have a yield point of 125,000# per square inch and were of uniform quality. The average calibration constant was 1.3 pounds per .0001 deflection. Since the variation from this constant was no greater than the limit of accuracy of the testing machine, this average figure was used in computing the pressures exerted on the panels in the silo. Since the deflectometer was equipped with both vertical and horizontal level glasses, it was possible to read the vertical and horizontal components of the forces acting on each 5/8-inch rod supporting the panels. The horizontal component was the lateral pressure exerted against that portion of a panel it supported and the vertical component was a measure of the weight of silage supported due to the friction between the silage and the panel.

Pressure readings were taken of both the horizontal and vertical forces on each panel for each 2 feet of silage placed in the silo, twenty complete sets of readings being taken while the silo was being filled with 125 tons of silage. These readings could be repeated with a variation of less than .0003 inches which represents 3.9#. Since the loads measured varied from 50 to 700 pounds on one rod the experimental error introduced would vary from 8% to 0.6%, and the average error when the depth of silage was 10 feet or more was 1-1/2% or less. There were variations in the panel pressures at different heights which were probably due to changes in the rate of filling, the moisture content of the corn and the amount of compaction in the silage. The maximum lateral pressure before the silo was opened was 300# per sq. ft., which occurred two days after filling and which lessened approximately 5 percent during the first month after filling and 5 percent the second month. The maximum vertical pressure was 154# per square foot and dropped about 10% during the first month of settling, and 2-1/2% the second month of settling. There was very little change in pressure thereafter until the silo was opened at the end of 3-1/2 months.

When the pressures on each panel with the same depth of corn above were averaged, the pressure on the walls per square foot for each foot of depth was found to be 8 pounds lateral and 5 pounds vertical. The results of these averages were plotted and gave the curves shown in figure 2. These curves are very similar to curves in figure 3 plotted from the pressures read on panel 1, the bottom panel as the head or depth of silage increased. In 1937 and 1938 the silo contained approximately 150 tons of silage, 25 tons more than in 1936, the greater weight being due to higher moisture and shorter length of cut, but the pressures were substantially the same.

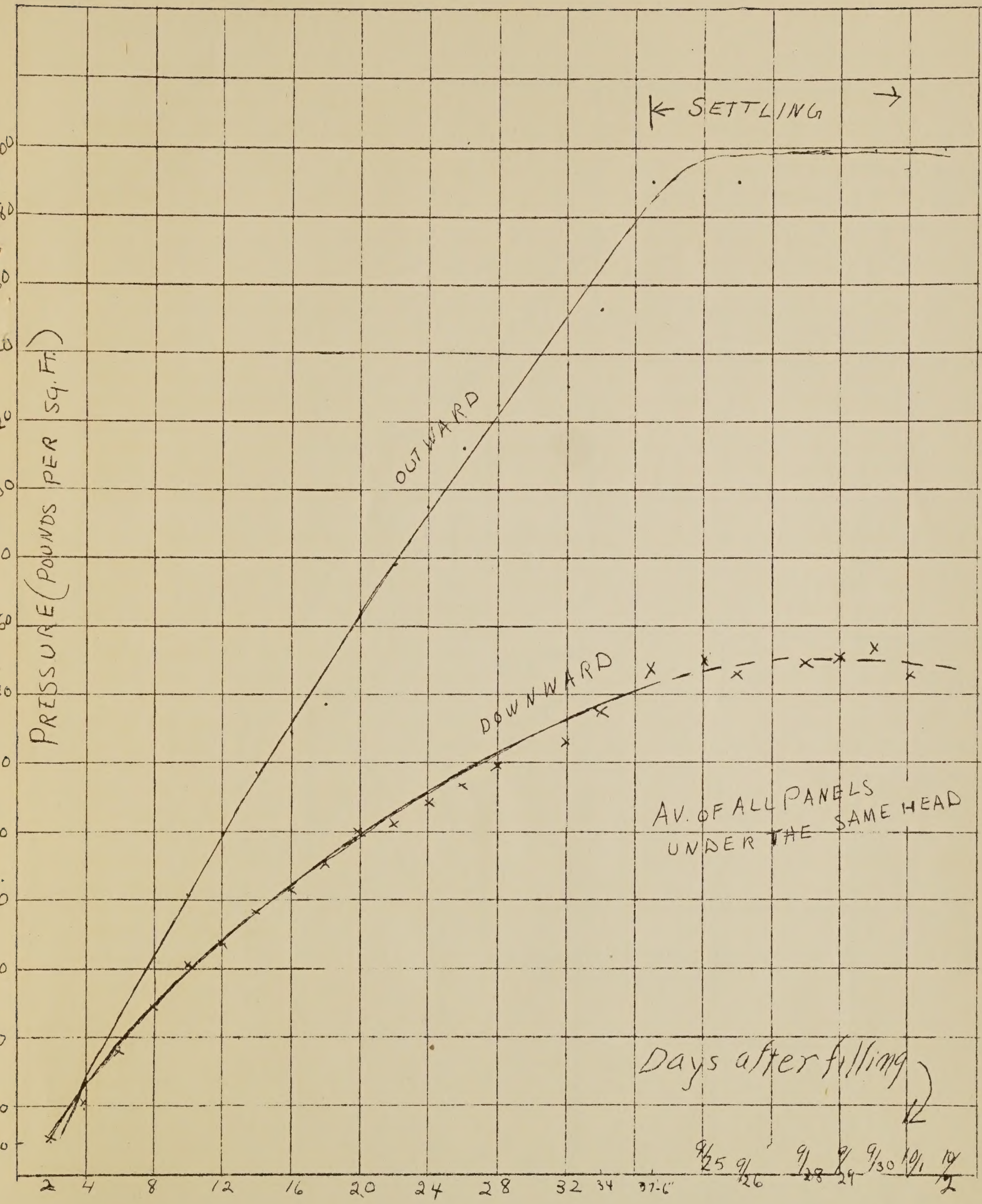


Fig. 2

Depth of Silage (Feet above bottom of panel)

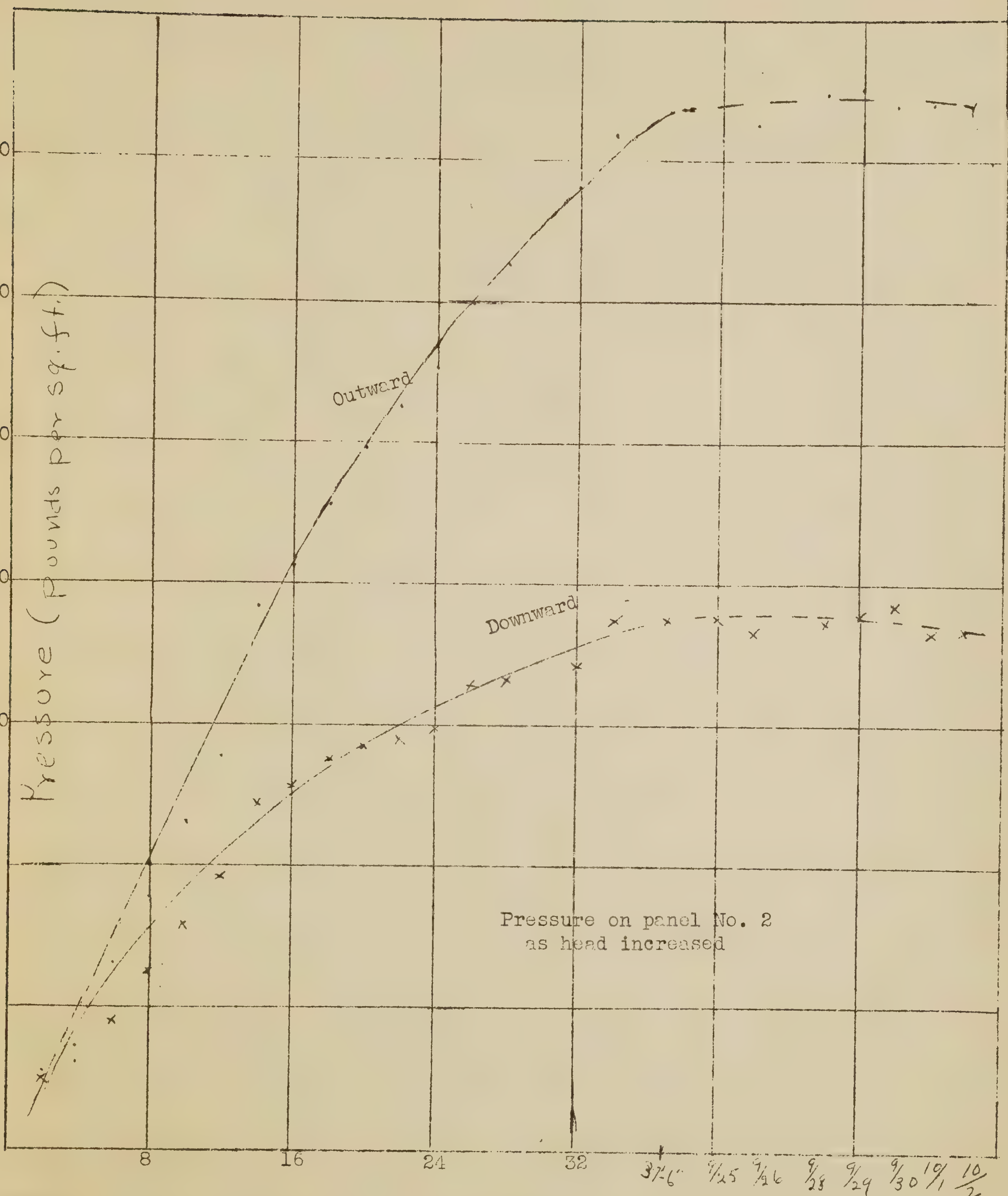


Fig. 3 Depth of Silage (Feet above bottom of panel)

Table 1 shows the approximate amount of silage placed in the silo at various depths and its density before and after settling. After 10 feet of silage had been fed out the pressure on the two top panels changed direction and pushed up on the panels. The amount of this reversed load increased as the top level of the silage approached the bottom of the door opening and is shown graphically by the vertical pressure curve in figure 4. This curve also shows how the lateral pressure increased as the head decreased. This increase was so large as to make the maximum lateral pressure approximately 350 pounds per square foot on the bottom panel, which is 50 pounds greater than the maximum pressure when the full silo had settled 2 days. This being quite unusual and unexpected, we offer the following explanation: Silage, like other coarse materials, arches between the walls of the silo giving a lateral pressure and a vertical pressure that is a product of the lateral pressure and the coefficient of friction between silage and the silo wall. As the silage settles these arches gradually flatten out and the maximum pressure occurs when the arches become flat, from one to three days after filling ceases.

As settling continues the center becomes lower than the edges, forming an inverted arch which allows the lateral pressure to decrease a small amount. In addition to this, the silage settles along the walls. Consider this action as if the ends of the arches were sliding down the walls of the silo, always remembering, however, that the center goes down more than the outside, the entire mass becoming very compact. When the silo is opened and a certain amount has been fed out, the silage starts to re-expand. This re-expansion is greater in the center and the compacted arches again tend to flatten out, becoming flat, thus giving the maximum pressure when there is approximately 4 feet of silage above the bottom of the door opening or 10 feet in the silo. Had the silo not had a pit, this maximum pressure may have occurred on the third or fourth panel rather than the bottom panel. On the other hand, it may have still occurred in the bottom or second panel and have been greater than was shown in this test. The curves in figures 3 and 4 substantiate this explanation. They show the pressures to increase during filling and the first 3 days of settling, they they gradually fall off until the silo is opened when the lateral pressure curve takes a decided swing upward. The vertical pressures show a slight increase until enough silage is fed out to start re-expansion when it starts to decrease and continues until the pressure reverses or becomes negative.

The work on grass or leguminous silage pressures started in July, 1937, when an 18 by 43-foot concrete-stone silo was filled with a mixture of oats and peas to which about 40 pounds of molasses was added for each ton of green material.

TABLE 1.

WEIGHT, DEPTH AND DENSITY OF SILAGE DURING FILLING

Weight Added	Total Weight	Depth	Volume	Density
	#	ft.	Cu.ft.	# / cu.ft.
9/19 - 21,850	21,850	7'-0"	1,078	20.3
9/21	21,850	5'-0"	770	28.5
9/21 - 57,435	79,285	20'-6"	3,157	25.1
9/22	79,285	17'-6"	2,695	29.4
9/22 - 68,835	148,120	31'-6"	4,851	32.3
9/23	148,120	27'-0"	4,158	35.6
9/23 - 70,850	218,970	40'-6"	6,237	35.2
9/24	218,970	36'-6"	5,621	39.0
9/24 - 21,475	240,445	45'-0"	6,930*	34.8
9/25	240,445	43'-0"	6,622	36.4
9/26 - 10,630	251,075	45'-0"	6,930*	36.2
9/28	251,075	43'-0"	6,624	37.9
9/29**	251,075	42'-0"	6,468	38.8

* Volume of space from plate to under side of conical roof estimated.

** Leveled and tramped 9/28/36, 4:00 P.M.

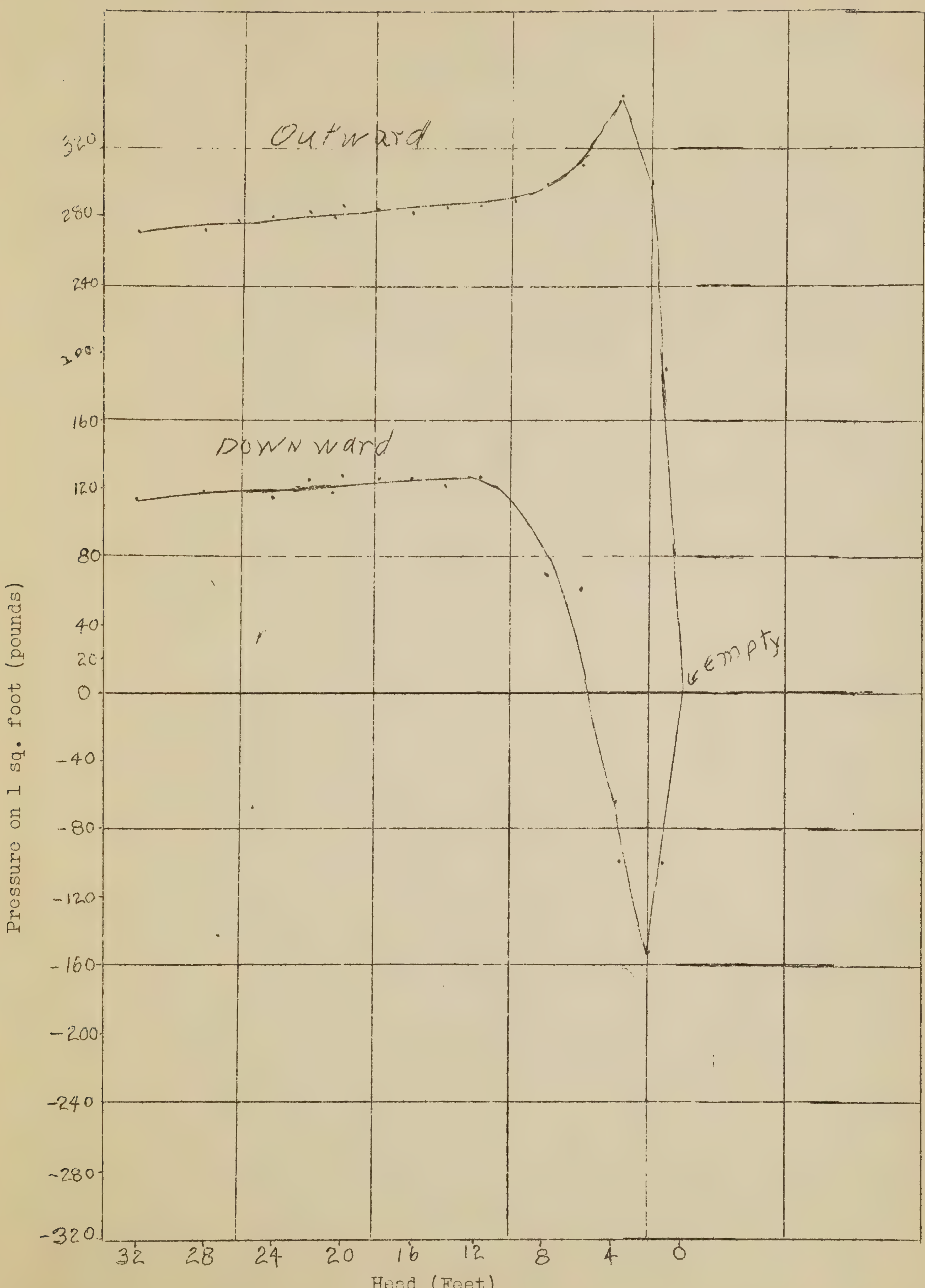

Outward
Downward
empty
320
280
240
200
160
120
80
40
20
0
-40
-80
-120
-160
-200
-240
-280
-320
Pressure on 1 sq. foot (pounds)
32
28
24
20
16
12
8
4
0
Head (Feet)

Fig. 4

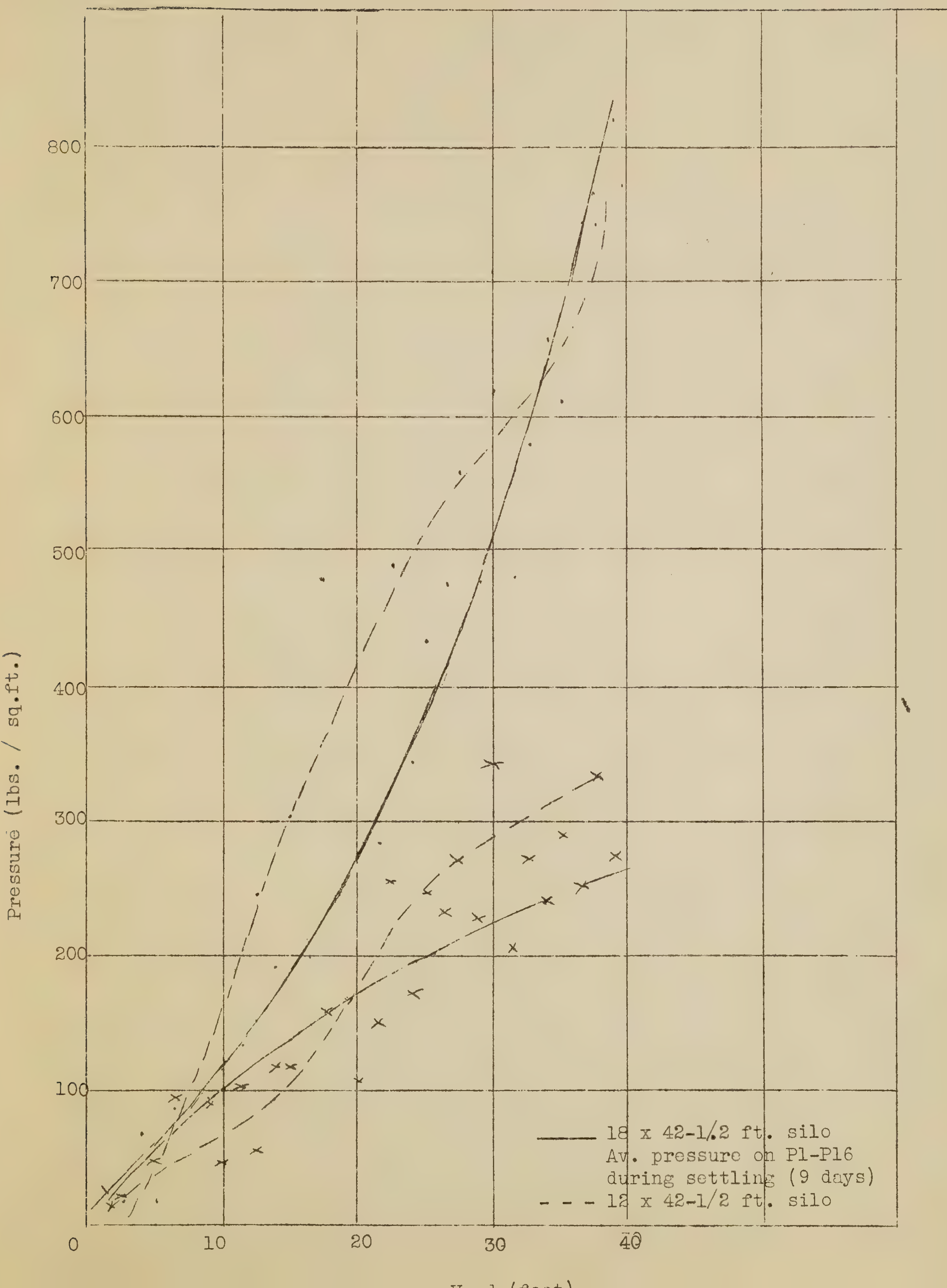
The pressure set-up was the same as described above except that the pressure panels were 29-1/2 by 21 inches, giving an area of 4.3 square feet, and the points of support 16 inches apart. The supporting rods were calibrated in the Mechanical Engineering laboratory at Rutgers University and found to give a deflection of .0001 inches for each 1.73 pounds of load.

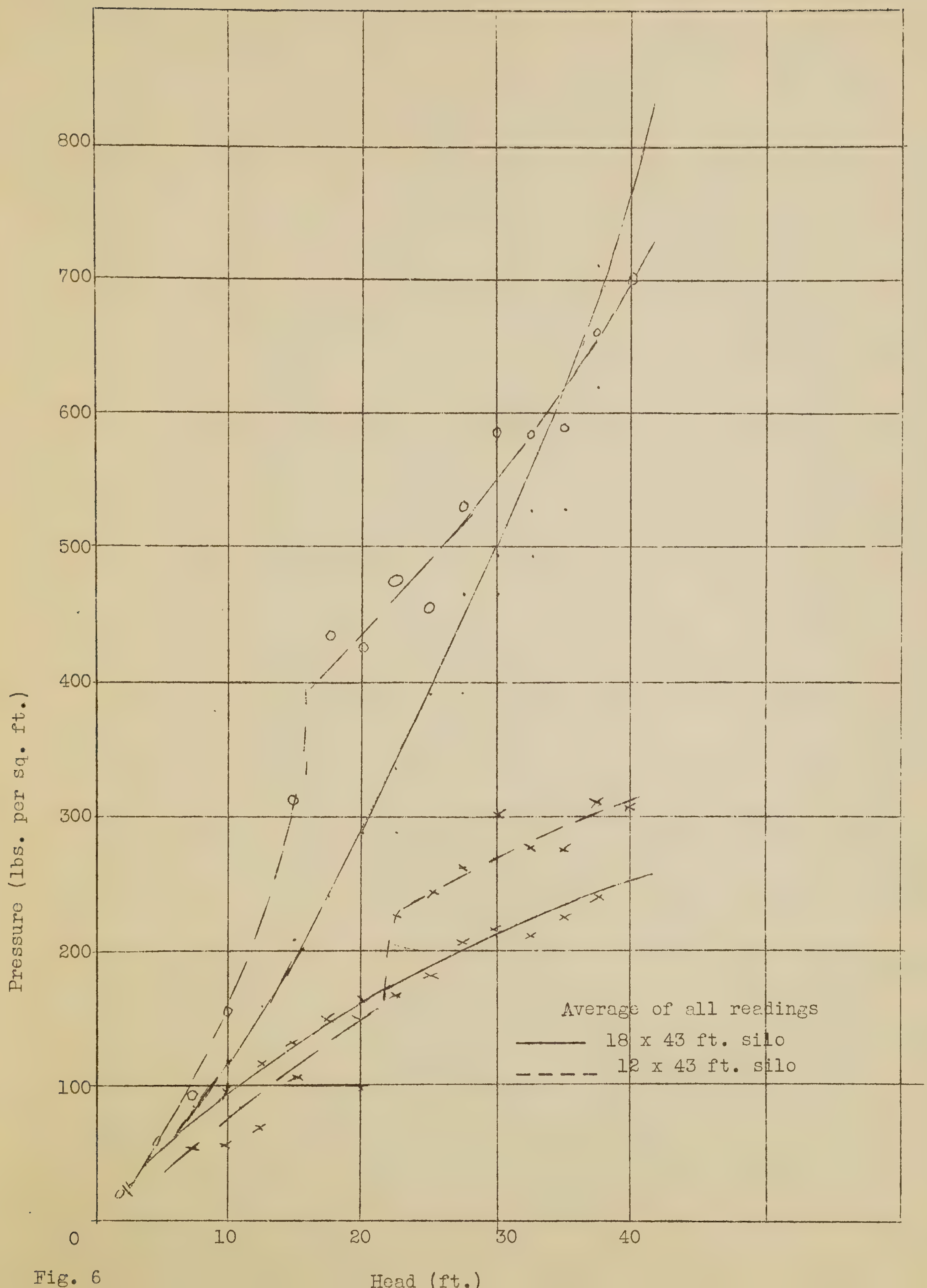
Zero readings were taken on each rod when a door was placed in the silo to allow for the weight of the door, and load readings were taken when the silage was level with each door. Readings were also taken in the morning to get the effect of settling on the pressures.

The silo was filled from July 6 to 19 and refilled on the 20th and 21st. The total content weighed 267.8 tons -- 262.6 tons of green material and 5.2 tons of molasses. The average moisture content of the oats and peas after the molasses was added was 71.9% and ranged from 68% to 79%. Silage juices and molasses drained from the silo doorway and through a few cracks in the bottom 5 feet of the silo for 2 or 3 weeks after the filling was completed. Settling went on until December 15 when the silo was opened and the silage was fed out till about the middle of August of this year. Since the silage was fed out slowly all data on the test has not been analyzed and cannot be included in this report.

Fig. 5 shows graphically the horizontal and vertical pressures on the 16 doors in pounds per square foot when the silo was full. Here too, as with corn silage, the pressures increased by different amounts, but as the head increased the horizontal pressure increased. The lack of uniformity in the increase of pressure for equal increments of silage, we believe to be due partially to one door taking part of the load of the one above or below it and partially to differences in the moisture content of the different layers of silage.

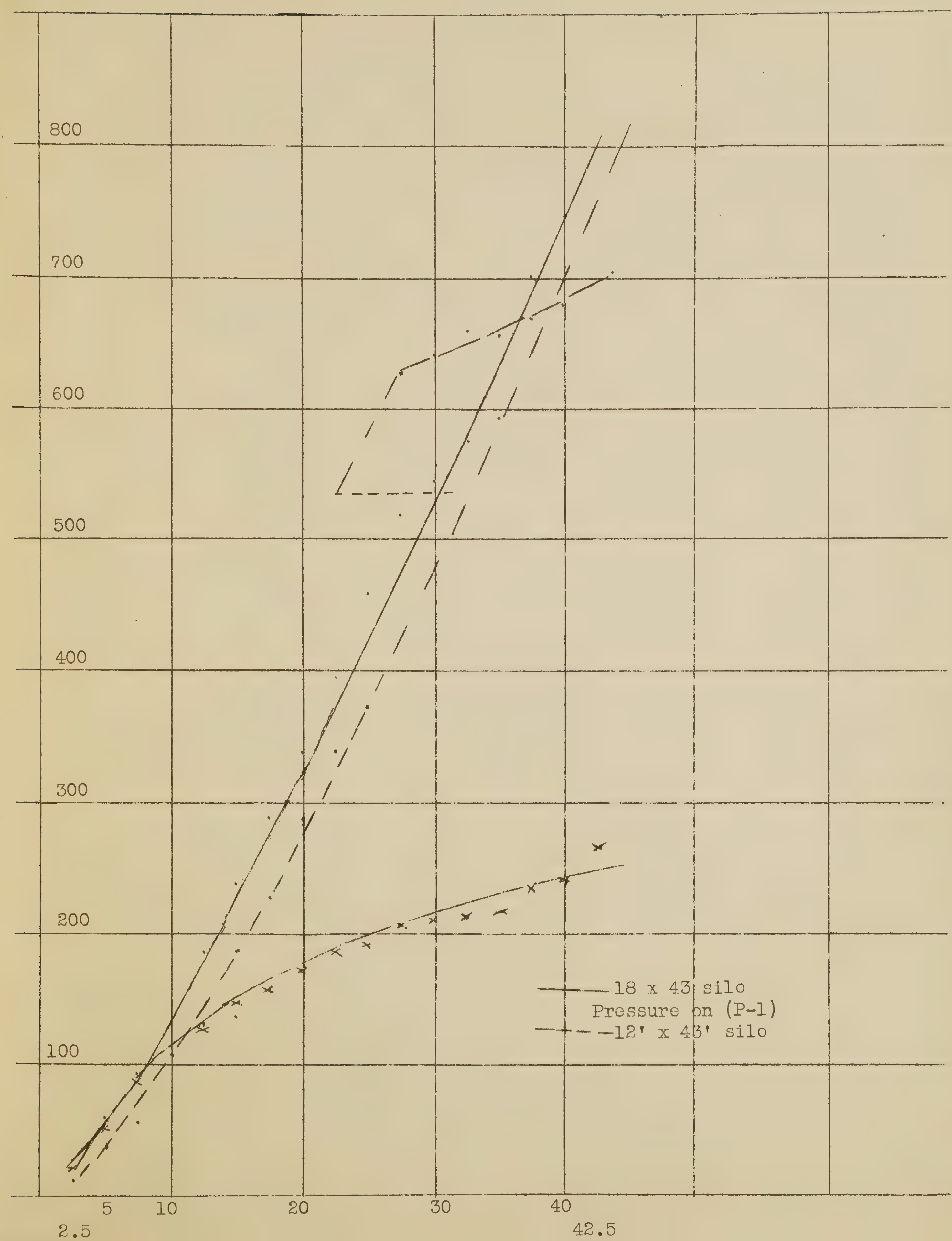
Curves plotted from the average pressures on all panels supporting the same head with the average pressures on panels 1 to 16 during settling, also curves of the pressures on panel 1 as the head increased, are shown in figures 6 and 7. These curves all follow the same general slope. The curve for the horizontal pressures on panel 1, as the head increases, approaches the straight line increase of 19 pounds per square foot for each foot of depth. The vertical pressures do not appear to be quite so uniform. They show an approximate average of 8 pounds per square foot per foot of depth for depths up to 25 feet and 6 pounds per square foot per foot of depth for depths from 25 to 42-1/2 feet.


800
700
600
500
400
300
200
100
Pressure (lbs. / sq.ft.)
0
10
20
30
40
18 x 42-1/2 ft. silo
Av. pressure on P1-P16
during settling (9 days)
12 x 42-1/2 ft. silo



800
700
600
500
400
300
200
100
0
10
20
30
40
Pressure (lbs. per sq. ft.)
Head (ft.)
Average of all readings
18 x 43 ft. silo
12 x 43 ft. silo

Fig. 6


800
700
600
500
400
300
200
100
5
10
20
30
40
2.5
42.5
18 x 43 silo
Pressure on (P-1)
12' x 43' silo

During unloading the horizontal pressures showed a slight tendency to increase but not enough to produce loads as great as during the first week of settling. As in the case of corn silage the vertical pressures on the top 4 or 5 panels started to go down, and the top and second panel pressures became negative. The reversed pressure lifted the door and gave upward measurable pressures up to 225 pounds. This indicated load was measured after all the lost motion in the panel supports was taken up and was actually greater.

During the past summer a 12 by 43-foot silo was equipped with pressure panels, and pressures were taken while it was filled with approximately 36 tons alfalfa and molasses silage, 85 tons of sweet clover, and 37 tons of oats and peas.

The pressures in this silo are represented in the figures by the broken line curves with the corresponding curves for the 18-foot silo. The distinct break in each curve may be due to the different material, moisture and a varying amount of compaction. The bottom 25 feet (partially settled) of the silo was filled with alfalfa containing 69 and 77% moisture. Above that depth sweet clover and alfalfa containing 80% moisture was added. At this point the pressures on panel #1 jumped from 373 to 628 pounds per square foot with the addition of just enough silage to raise the level of the silage from a 23-1/2 foot level to the 27-1/2 foot level. The silo had been filled to 25 feet one evening, settled to 23-1/2 feet, and was refilled the following morning to a depth of 27-1/2 feet. Curves of the vertical pressures show the same characteristics.

The density of grass silage cannot be calculated without a careful analysis of the moisture content of the silage when fed out and will be reported on at a later date.

Temperature Studies

When molasses silage investigations were initiated at the New Jersey station in 1934 it seemed advisable at that time to observe the temperature developed in low moisture silage as compared to high moisture silage. Lately this work has been expanded to include comparison of temperatures in molasses silage and phosphoric acid silage.

The early temperature study was reported in the Journal of Dairy Science, February, 1936, Vol. XIX, No. 2. In this test, 30 tons of green material, consisting of good alfalfa and mixed grasses at an average moisture content when ensiled of 66.8 percent, was placed on top of some corn silage of the previous year. On top of this high moisture silage was placed approximately 16 tons of similar material at an average moisture content of 44.4 percent. Molasses was added at the rate

of 40 pounds per ton of green material as ensiled. Filling was completed on October 9. Five iron-constantan thermocouples were placed at various heights in each layer. Temperatures were read twice daily for 19 days after filling and at greater intervals until the silage was fed out the following March and April.

After 17 days the temperature range in the low moisture silage was from 115° F. near the center to 144° F. near the top. For nearly a month after this the temperatures showed a downward trend but during the latter part of November they started up and were still going generally upward when the silos were opened March 10. The maximum temperature recorded was 160° F. All thermocouples indicated temperatures of over 130° F. at some time. Most of the silage in this section was unfit for feeding, much of it was brown in color, some of it black and charred.

The maximum temperature of 109° F. in the high moisture section was reached about 5 weeks after filling. This was near the center of the mass. From November 15 the temperatures were generally downward. It is certain that this maximum temperature is well below the allowable maximum but it has been impossible to find a report of any tests that indicate the temperature above which serious losses occur in the food value of the silage. Investigators at the New Jersey Experiment Station are of the opinion that temperatures below 140° F. are safe.

Supplementing the New Jersey investigation of 1934, a test was instigated in June 1938 to measure the temperatures developed in molasses silage as compared with phosphoric acid silage. Two 14 by 30-foot silos are being used for the test. One was filled with 78.49 tons of green timothy with molasses added at the rate of 104.13 pounds per ton of green material. The second was filled with 81.44 tons of green timothy with 16.28 pounds of phosphoric acid per ton of green material. Five thermocouples were placed in each silo 5 feet from the silo wall and at 5 foot intervals with the last thermocouple about 6 feet from the top of the silage. The molasses silage was ensiled on June 13 to 16, the phosphoric acid silage on June 15 to 20. Temperature readings were taken daily for 19 days after filling, then at less frequent intervals. The maximum recorded temperature of 113° F. in the molasses silage was reached on June 24. This occurred 10 feet from the bottom of the silo. The minimum of 103° F. at that time occurred 5 feet from the bottom of the silo. In the acid silage the temperature reached 108° F. at the top thermocouple but only 90° F. at the center thermocouple on June 25. After reaching the maximum, the temperatures at all points except the top in both silos have moved generally downward. After 9 weeks the temperature at the top thermocouple in both silos has leveled off at 103° F. while the temperatures at the other 4 points in both silos ranged between 83° and 91° F. Readings will be continued until the silos are opened sometime during the winter. These observations indicate that, while the temperature in the molasses silage is slightly but not significantly higher than acid silage, it has never reached a point in either the molasses or acid silage where loss in food value is likely to occur due to heating.